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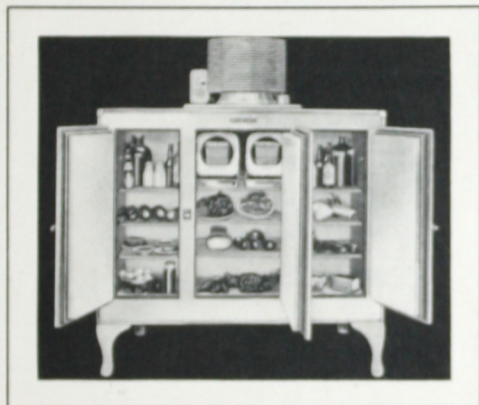
REFRIGERATION



By A. R. STEVENSON, Jr.

GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y.

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Refrigeration

Natural Refrigeration Through Ice—Early Ice Machines—Electric Analogy for Refrigerating Cycle—Thermal Characteristics of Ice Boxes—Domestic Refrigerators

By A. R. STEVENSON, JR.

ENGINEERING GENERAL DEPARTMENT
GENERAL ELECTRIC COMPANY

COLD is the opposite of heat. It is interesting to compare Nature's method of storing them both. During a geological age called the "Carboniferous Period," the sun's heat produced a luxurious plant growth which absorbed carbon from the atmosphere. This plant growth, buried under the ground during long ages, petrified into coal, thus making reservoirs where the sun's heat was stored. The burning of a piece of coal may be considered as the releasing of the "bottled sunshine" of a long past age. Unfortunately there is no simple effective means by which the heat of each summer of the present age can be stored locally for use during the following winter.

But in ice the cold of each winter may be stored locally for refrigeration during the succeeding summer. Ice freezes on the surfaces of rivers and lakes, where it can easily be cut and floated to a warehouse. It is not necessary to dig into the ground, although sometimes a few feet of snow have to be removed before cutting can begin.

The use of ice for preserving food products was not very general until the beginning of the nineteenth century, and even today the use of ice for refrigeration is not extensive in the countries of Europe.

After the construction of the first large ice house in America in 1805, there grew up rapidly an industry which harvested the ice in our northern states and shipped it to the South in sailing vessels. As early as 1850, the city of New Orleans alone required over 50,000 tons annually, at prices ranging from \$15.00 to \$20.00 per ton. The ice harvest in the State of Maine during the winter of 1879-80 amounted to 1,300,000 tons, largely supplied by twenty-six firms on the Penobscot river and fifty-three firms on the Kennebec river. In 1880, there were about 160 ice houses on the Hudson river.⁽¹⁾

The history of refrigeration is the story of a battle between nature and the efficiency of a machine. It is interesting because it demonstrates what can be accomplished mechanically when all of the requirements have been studied and successfully met. Here again, electricity is the last word in performance.—Editor.

The Civil War cut off the supply of natural ice to the southern states, and the small amount of ice available sold at about five cents a pound. This at least partially explains the interest in artificial production of ice which sprang up in the South about 1863.

A century ago, natural ice was almost the only commercial means of producing refrigeration, but today almost everywhere artificial ice is replacing the natural product.

The banks of rivers and lakes are lined with abandoned ice houses. The three chief reasons for this change are:

- Rise in labor costs.
- Improved utilization of power.
- Improved generation of power.

Labor was the largest factor in the cost of natural ice. But labor is only one-quarter of the cost of artificial ice made in a modern electrically operated plant.

Ferdinand Carré invented the intermittent absorption ice machine in 1860; and in 1862 he made the process continuous by the addition of an absorber and circulating pump, as illustrated in Fig. 2. Shortly after this invention several machines of the Carré system were imported to the southern part of the United States. There are still many ice plants operating on this absorption principle.

By far the great majority of ice plants today, however, are of the compression system. The ammonia compression machine was patented in France in 1864. But it was not until about 1870 that Dr. Carl Linde, in Germany, and David Boyle, in America, produced the first practical compression machines. These were, of course, steam-driven and had the general arrangement shown in Fig. 3.

⁽¹⁾ Many of the historical data given in this article have been derived from "History of Refrigeration," by J. C. Goosemann, a series of articles appearing in *Ice and Refrigeration*, beginning in April, 1924.

have been made in improving the efficiency of large generating stations, some of which are already at least three times as efficient as a small steam engine. Through the many improvements in generating apparatus, much less coal is used to produce the same power, and the labor cost is reduced by labor-saving devices. It has thus been possible for the price of electricity to remain nearly constant, while the prices of almost everything else, including coal and labor, have gone up. Because of the low price of electric power, the majority of new ice plants and many of the old steam plants are being electrified.

The compressor room of a modern electrically driven ice plant is shown in Fig. 4. The cooling tower on the roof is shown in Fig. 5, and a diagram of the brine tank and auxiliary apparatus is shown in Fig. 6.

Table III shows the division of the cost of producing ice in an electrically operated plant,⁽³⁾ while in Table IV⁽⁴⁾ is given the allocation of the kilowatt-hours per ton of ice in such a plant.

TABLE III
COST OF ICE IN ELECTRICALLY
OPERATED PLANT

	Per Cent
Labor.....	25
Electric power.....	27
Ammonia and supplies.....	7
Fixed charges.....	41
Total.....	100

TABLE IV
KILOWATT-HOUR CONSUMPTION IN JULY
PER TON OF ICE

Kilowatt-hours for ammonia compressor.....	43.00
Kilowatt-hours for air compressor for agitating raw water in cans.....	6.08
Kilowatt-hours for water pump.....	3.33
Kilowatt-hours for brine agitator.....	3.05
Kilowatt-hours for hoists, etc.....	1.93
Total kilowatt-hours.....	57.39

Omitting the auxiliaries, let us consider the energy input to the ammonia compressor as given in Table IV. Then

⁽³⁾ By H. Sloane, in the *Refrigerating World*, December, 1920.
⁽⁴⁾ By Van R. H. Greene, in the *Refrigerating World*, 1921.

$$43 \text{ kilowatt-hours} = 147,000 \text{ B.t.u.}$$

Amount of heat necessary to be removed from 1 ton of water at 32 deg. F. to transform it to ice at 32 deg. = 288,000 B.t.u.

$$\text{Apparent efficiency} = \frac{288,000}{147,000} = 196 \text{ per cent}$$

Of course, there is no excuse for calling the above quotient efficiency. It is true that

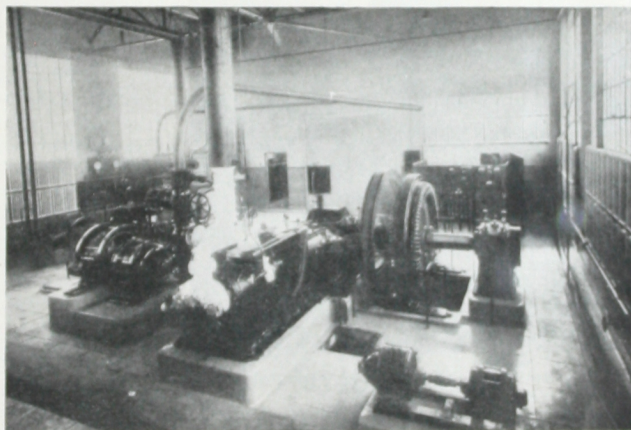


Fig. 4. Compressors in a Modern Ice Plant, Showing Synchronous-motor Drive

288,000 B.t.u. have to be removed from the water in order to freeze a ton of ice, but this is only an energy transfer. About a century ago, Carnot stated the following law:

$$C = \frac{T_1}{T_2 - T_1} = \frac{\text{Refrigerating effect at } T_1 \text{ deg.}}{\text{Work to pump the heat to } T_2 \text{ deg.}}$$

where C is known as the Carnot coefficient of performance, and the temperatures are expressed in degrees absolute.

A temperature difference is necessary for a transfer of heat, and in an ice plant the ammonia would have to be about 10 deg. F. in order to rapidly freeze ice at 32 deg. F. The heat pumped out of the ice would probably be delivered to the surrounding air through a cooling tower which would very likely run at a temperature of about 110 deg. F.

Then

$$T_1 = 10 + 460 = 470$$

$$T_2 = 110 + 460 = 570$$

Substituting these figures, the Carnot theoretical coefficient performance would be,

$$C = \frac{470}{570} = 4.7$$

$$100$$

It is thus seen that the ice plant which, at first glance, seemed to have an efficiency of 196 per cent, actually had what could have been called a coefficient of performance of

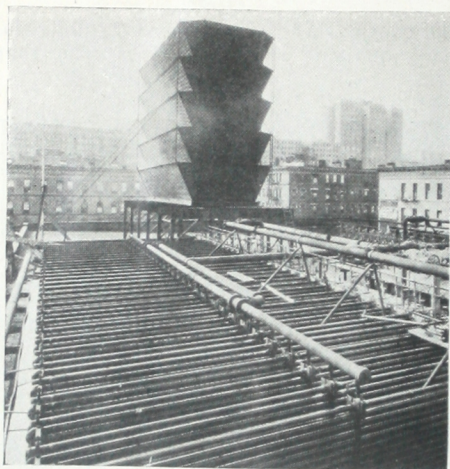


Fig. 5. Outdoor Tower for Cooling the Compressed Refrigerating Gases

1.96, whereas the theoretical coefficient of performance is 4.7. This ice plant, therefore, was only 42 per cent as efficient as a theoretically perfect plant operating between the same temperatures.

The conception of theoretical coefficients of performance depending upon absolute temperatures may be illustrated by an electrical analogy. Fig. 7 shows, side by side an electrical diagram and a refrigerating machine

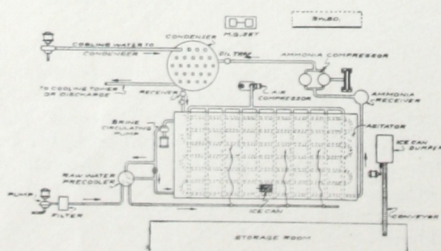


Fig. 6. Diagram of Brine Tank and Auxiliary Equipment for Making Artificial Ice

diagram. The analogy is made between a booster generator pumping electric energy from one storage battery at a lower voltage

to another storage battery at a higher voltage, and a refrigerating machine pumping heat from an ice box at one temperature to the outside air at a higher temperature. If the energy removed from the lower voltage battery is divided by the energy required to drive the booster generator, there is obtained a coefficient of performance of 4.8 which is analogous to the coefficient of performance for the refrigerating machine and which

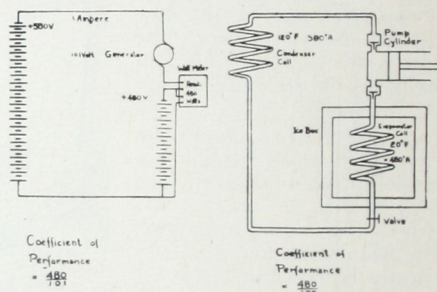


Fig. 7. An Electrical Analogy for the Refrigerating Cycle

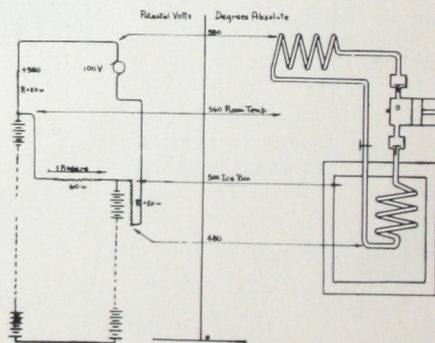


Fig. 8. The Electrical Analogy in Greater Detail

depends upon the potential of the battery terminals above their common connection. Thus,

$$C = \frac{E_1}{E_2 - E_1}$$

In Fig. 8 are shown more elaborate diagrams where the analogy is carried still further, resistance drops being included in the electrical diagram to correspond to the temperature differences necessary to produce heat transfer in the refrigerator diagram. It is hoped that this analogy may serve to clarify some of the

thermodynamic conceptions which are often difficult to keep clearly in mind. For instance, it is hard to get a physical conception of entropy until we see that its flow may be compared to the electric current, because the product of the flow of entropy by temperature and the product of current by voltage both represent power.

ICE BOXES

A generation ago, spring houses, cold cellars, etc., were used extensively for the preservation of food; and they are still used today, especially in country communities. In the majority of modern homes, however, the ice box is taken for granted as the proper method of preserving food, and there is no doubt that food can be very well preserved in a well-insulated ice box. Unfortunately, however, the great majority of ice boxes are not well insulated. The following quotation from a paper⁽⁵⁾ by Dr. John R. Williams, Secretary of the Milk Commission, Rochester, New York, is of interest:

"The majority of domestic refrigerators are inefficient because they consume too much ice and do not maintain a temperature low enough to prevent food from spoiling. The chief explanation of their inefficiency is to be found in the lack of sufficient and proper insulation.

"The waste from ice meltage because of improper insulation of refrigerators in Rochester homes (population of city, 230,000) amounts to 60,000 tons yearly, or about \$350,000.

"Money invested in insulation will be returned many times in the saving in ice bills. Added insulation means not only economy in ice consumption, but also lower temperature in the refrigerator and the less spoiling of food."

Some of Dr. Williams' conclusions are confirmed by calculations plotted in Fig. 9, which show the improvement in temperatures and the saving in ice effected by adding insulation to an ordinary 100-lb. ice box. One inch of corkboard over the area of this box would total 42½ board-feet. This extra inch of cork insulation could have been furnished with the box at an additional selling price of about \$20. Assuming 6 per cent interest on the investment and 10 per cent depreciation, it is found that the annual fixed charge on

this extra inch of insulation would be \$3.20. But, to offset this, better refrigeration is obtained and 6.25 lbs. of ice per day are saved. Assuming that the box is used during six months of the year, the annual saving is 1140 lbs., which at 60 cents per hundredweight corresponds to a saving of \$6.85 worth of ice, or a net saving of \$3.65. This is 18 per cent on the investment, as well as a guarantee of better refrigeration. Similar calculations show that with three additional inches of cork insulation, the net saving would be \$2.55, which is 4¼ per cent on the \$60 additional investment.

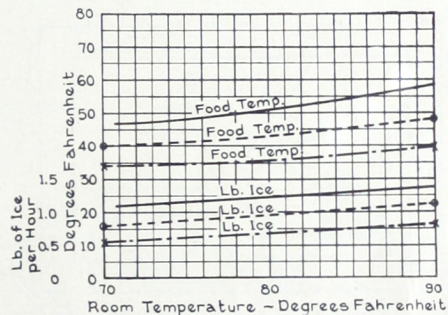


Fig. 9. Effect of Additional Insulation Upon the Economy of the Ordinary Ice Box

In the design of any ice box, the question always arises as to what allowances should be made for the doors. The doors are the source of three types of loss:

- (a) Spilling of cold air when the door is opened
- (b) Leakage due to badly fitting doors
- (c) Conduction through the door frames which, of necessity, are badly insulated.

The first of these is not so serious as is generally supposed. Consider a box having 6 cu. ft. internal volume, operating at 40 deg. F. Assume that when the door of the box is opened all the cold air spills out and is replaced by air at 70 deg. F. and 66 per cent humidity. The question is how much refrigeration will be required to cool this new air from 70 to 40 deg. F., and condense the water vapor. Six cubic feet of air at 70 deg. would weigh about 0.45 lbs. Since the specific heat of air at constant pressure is 0.24, it would be necessary to remove 3.24 B.t.u. in order to cool this air 30 deg. But this air originally contained approximately 0.00454 lb. of water

(5) "A study of Refrigeration in the Home and the Efficiency of Household Refrigerators," read before the Third National Congress of Refrigeration, in 1913.

vapor, and when it is cooled to 40 deg. it is incapable of holding more than 0.00246 lb. of water vapor. The difference must be condensed and the latent heat of vaporization at these temperatures is approximately 1060 B.t.u. per pound. The condensation would, therefore, require 2.2 B.t.u. The total refrigeration required to cool the air and condense the water would, therefore, be about 5.44 B.t.u., or 0.0378 lb. of ice. If the box were opened twenty-five times in the course of the day and entirely filled with warm air each time, less than a pound of ice, or only about 2 or 3 per cent of the total daily ice meltage in the box, would be needed to cool this air.

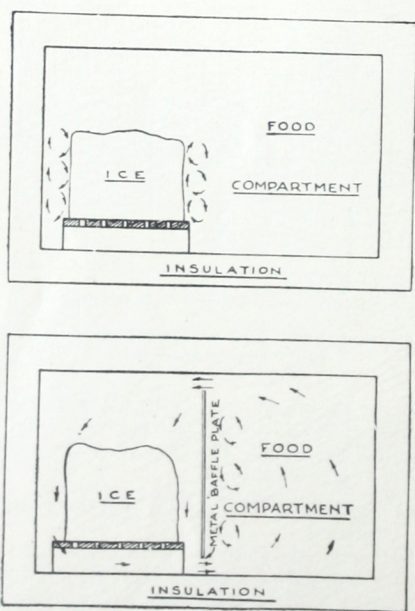


Fig. 10. Principle of the Baffle in the Ice Compartment*

An extreme case would be represented by a refrigerator operating in a 90-deg. room with 100 per cent humidity, under which condition the refrigerating effect required to cool the air and condense the moisture would be approximately 16.8 B.t.u. If the 0.011 lb. of condensed moisture were also frozen in the process an additional 1.6 B.t.u. would be required, making a total of 18.4 B.t.u., or

0.128 lb. of ice for each opening. If the box were opened twenty-five times, this would be 3.2 lb. of ice per day, which is less than 6 per cent of the probable meltage of ice in the box. Such calculations lead us to believe that the effect of opening the doors is not likely to be more than 10 per cent.

Leakage due to badly fitting doors can, to a large extent, be overcome by the use of cushion gaskets.

The conduction of heat through the door frames is much more serious. Calculations and tests seem to indicate that, even in a very well-constructed four-door box, the heat conduction through the door frames, which of necessity are badly insulated, is between 25 and 35 per cent of the total leakage. If "all-metal" refrigerator boxes have metal flashing along the door edges, sills, and jams, forming a metallic connection between the sheet-steel lining and sheet-steel exterior, this loss by conduction is likely to be greater than the total leakage through the walls of the box. This loss can be practically overcome by making the metal door edges of very thin high-resistance material arranged so as to make a long path for the heat flow.

One of the difficulties in attempting to make a vacuum refrigerator is the sealing of the door edges.

Another important point is the number of doors on the refrigerator box. The opening of one small door out of four may spill less air than the opening of one big door, but the four small doors have double the perimeter of door frames that the one big door has, and it is very difficult to insulate properly the cross pieces between the doors. Of course, one door would be unwieldy on a large box; but when an extra price is asked for a small ice box with several small doors, so small that platters have to be tipped on edge to go through the openings, with the idea that this arrangement is more efficient than a less expensive refrigerator with one door large enough to form a convenient opening, it would appear that a mistake is being made.

The ordinary ice box usually has a baffle, as illustrated in Fig. 10. The baffle is necessary because the ice, especially after some of it has melted, does not reach to the top of the box and a layer of warm air would be left above the level of the ice. But, as will be seen later, a baffle is not required and is, in fact, a detriment in an artificially refrigerated box where the cooling element reaches all the way to the top of the box all the time.

*This illustration, together with several of those which follow, was taken from Hull's *Household Refrigeration*.

Natural Refrigeration Without Labor

Whether ice is harvested from a natural source or made in an artificial ice plant, the actual cost of ice is very small compared to the cost of retailing it. The price of ice in cities is approximately 60 cents per hundred-weight, and at least half this price is the delivery cost. In widely scattered communities the price is still higher, largely because of the higher delivery cost.

Professor Elihu Thomson suggested a scheme whereby the cold of each winter could be stored for use in cooling a refrigerator the next summer, without any transpor-

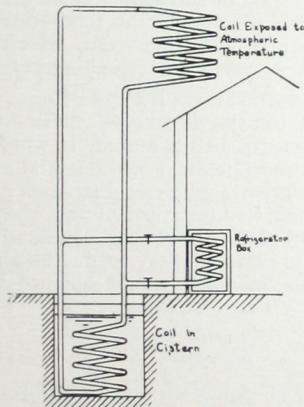


Fig. 11. A Theoretical Scheme for Automatic Refrigerator in the Home

tation or labor. A radiator placed on the roof of the house would be connected to a coil of pipe in an underground cistern, as shown in Fig. 11. On cold days, the wintry weather would cool the brine in the radiator, causing it to circulate downward into the coil in the cistern, which would gradually collect a thicker and thicker coating of ice. On warm days, the brine in the radiator would be lighter than the brine in the cistern coil and there would be no tendency to circulate. Thus, during the winter each cold day would add to the layer of ice being gradually stored in the cistern. In the summer, a motor-operated brine pump could be used to circulate the brine from the cistern to the refrigerator box, and the heat abstracted from the box would be absorbed by the gradual melting of the accumulation of ice in the cistern.

Domestic Refrigerating Machines

It is only during comparatively recent years that domestic refrigerating machines have begun to be seriously considered, and there are now about 104 companies either manufacturing or about to manufacture domestic refrigerating machines. There are a great many different types under consideration, a rough classification of which is given in Table V.

TABLE V

Vapor Compression Machines:	
(a) Conventional type using a stuffing box and electric motor.....	46
(b) Using a stuffing box and a water motor.....	1
(c) Stuffing box eliminated by enclosing the motor in the machine.....	17
(d) Stuffing box eliminated, but motor outside.....	7
	71
Absorption machines.....	22
Compressed air machines.....	4
Unknown.....	7
Total.....	104

Approximately 6 kw-hr. through the medium of one of these small electrically-driven compression machines has a refrigerating effect equivalent to the melting of approximately 100 lbs. of ice. A comparison of the cost of producing household refrigeration by various methods is shown in Table VI.

TABLE VI

	Average Operating Cost of producing Refrigeration Equivalent to the Melting of 100 Lbs. of Ice
Ice, at 60c per hundredweight.....	\$0.60
(1) Electrically operated, air-cooled compression machine, 6 kw-hr. at 3c per kw-hr.....	0.18
Water-operated compression machine—720 cu. ft. at 4c per 100 cu. ft.....	0.29
(2) Electrically heated, water-cooled absorption machine—12 kw-hr. at 3c per kw-hr., neglecting cost of water.....	0.36
Electrically heated, air-cooled absorption machine—24 kw-hr. at 3c per kw-hr.....	0.72
Gas-heated, water-cooled absorption machine—133 cu. ft. at \$1.35 per 1000 cu. ft., neglecting cost of water.....	0.18
Gas-heated, air-cooled absorption machine—266 cu. ft. at \$1.35 per 1000 cu. ft.....	0.36

In Table VI the figures are based on the actual cost of electricity, water, and gas in the city of Schenectady. The cost of water for the

absorption machines has been neglected because only 25 to 75 cu. ft., per 100 lbs. of ice, at 4 cents per 100 cu. ft., would be used.

There are no air-cooled absorption machines on the market and the figures given are the roughest kind of engineering estimate, although experience would probably show them to be approximately correct.

The figures as to the amount of water required by the water-motor operated machine are an engineering estimate, but since it is not very difficult to calculate how much water is necessary, the estimate is believed to be within reason.

The compressed-air machines are not included in Table VI. One of them might be compared in efficiency with the vapor compression machines.

The inefficiency of the absorption machines is largely inherent and might be explained as follows: Whereas the electrically driven compression machine, in spite of the low electrical efficiency of small motors and the poor mechanical efficiency of small compressors, actually utilizes about 20 per cent of the electric energy in pumping the gas, the absorption machine utilizes only about 10 per cent of the energy put into the electric heating unit in pumping the gas. It must be remembered that the absorption machine, although chemical by nature, actually has to perform the mechanical work of pumping the refrigerant from a low pressure to a high pressure. The vapor is sucked into a cold medium (usually cold water), and then the medium is heated, causing the vapor to be expelled under pressure. The high-grade electric energy, however, is not used directly to cause this pumping action, but is first degraded into heat and then the heat is used to produce mechanical work. The efficiency of any device for changing heat into mechanical work is inherently very low. A perfect heat engine has a very low theoretical performance given by the Carnot formula:

$$\text{Carnot efficiency} = \frac{T_1 - T_2}{T_1}$$

where

T_1 = the high temperature in degrees above absolute zero

T_2 = the low temperature in degrees above absolute zero

The efficiency is therefore seen to depend on the temperature range, which with these absorption machines is from 212 deg. F. to a

temperature that might be as low as 85 deg. F. if water cooling is employed. Therefore,

$$T_1 = 460 + 212 = 672 \text{ deg. absolute}$$

$$T_2 = 460 + 85 = 545 \text{ deg. absolute}$$

$$\text{Carnot efficiency} = \frac{672 - 545}{672} = 18.9 \text{ per cent}$$

It is thus seen that an absolutely perfect water-cooled absorption machine would have about the same efficiency as the present imperfect compression machines. But, just as it is difficult to make a small compression machine where the useful work is more than about 20 per cent of the input, so up to the present it has been impossible to make an absorption machine which approaches its theoretical efficiency. The actual efficiency of compression of the water-cooled absorption machines is about half the theoretical figure, or approximately 10 per cent. Of course the coefficient of performance is higher.

There are no air-cooled absorption machines available, but the theoretical efficiency of such a machine can be estimated. It would probably be uneconomical without the use of a fan to furnish enough cooling area to bring the internal temperature of the absorber to within 30 deg. above the surrounding air. Therefore, in an 80-deg. room, the air-cooled absorption machine would operate between 212 and 110 deg. F. Thus:

$$T_1 = 460 + 212 = 672$$

$$T_2 = 460 + 110 = 570$$

$$\text{Carnot efficiency} = \frac{672 - 570}{672} = 15 \text{ per cent}$$

Therefore, the air-cooled absorption machine would have only three-quarters the theoretical efficiency of the water-cooled machine. The ratio of actual to theoretical efficiency would be much smaller for the air-cooled machine than for the water-cooled, because the air-cooled machine could not be so well insulated during the heating period and the weight of material, such as cooling fins, etc., which would have to be heated and cooled in an intermittent machine, would be greater. Thus where the actual efficiency of the heat engine in a water-cooled absorption machine is about 10 per cent, the actual efficiency in the air-cooled absorption machine would be about 5 per cent.

It would appear that, until some further improvement in the efficiency of absorption machines is made, the cost of operating them electrically will be materially greater than that of compression machines. But figures seem to indicate that 11 cu. ft. of gas burned in an absorption refrigerating machine will produce about the same refrigerating effect as 1 kw-hr.

used to heat the same machine electrically. Eleven cubic feet of gas cost about half as much as 1 kw-hr.; therefore, the water-cooled

ing machines and boxes. It was decided some time ago to design the machines and boxes for a 90-deg. room temperature, in order not to

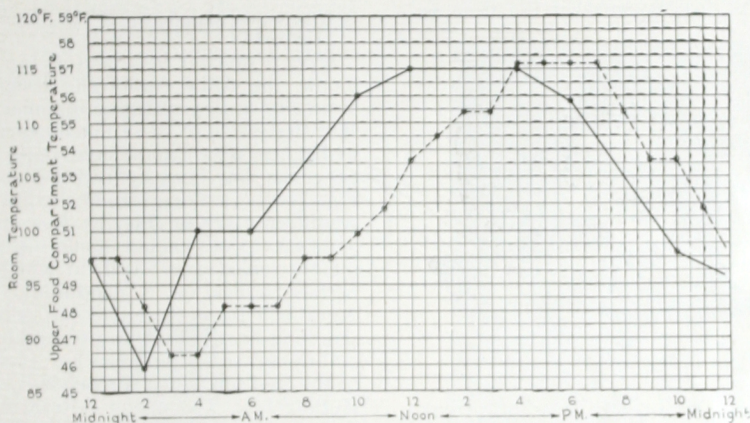


Fig. 12. Temperature Chart of a Hot Day in Southern California
Dotted line indicates the lagging temperature inside an ice box

absorption machine, when heated by gas, is competitive with the compression machines. But water cooling is an added complication, and the foregoing figures seem to indicate that, without further improvements, an air-cooled absorption machine, even when gas heated, would be expensive to operate.

Ice-Box Temperature Requirements.

It is generally admitted that the temperature of the

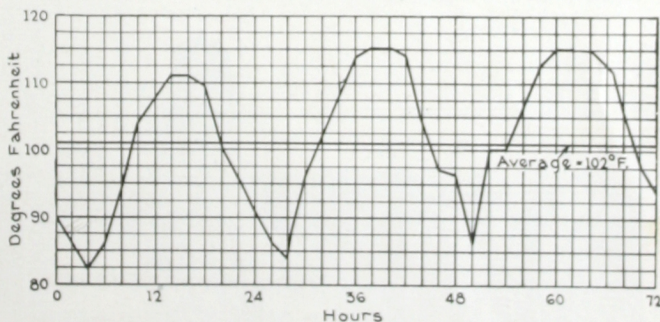


Fig. 13. Highest 3-day Summer Temperature Range at Trona, California

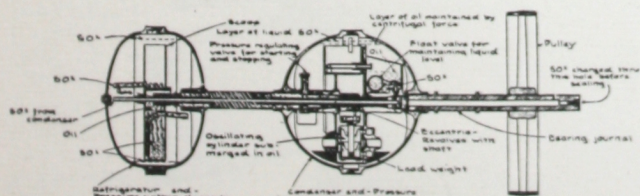


Fig. 14. Cross Section of the Audiffren Self-contained Refrigerating Unit

food compartment in a refrigerator should be maintained below 50 deg. F. in order to prevent multiplication of bacteria. The question immediately arises as to what room temperatures should be considered in design-

penalize the majority of users in the United States where temperatures only for very short periods exceed 90 deg. F. It takes time for heat to leak through the walls of a well-insulated refrigerator box. Therefore, when the temperature rises for a few hours at midday, the effect on the refrigerator is not so serious as might be supposed.

Having designed the machines for a 90-deg. room temperature, the further question arose as to how the machines would perform in still higher temperatures. The hottest temperature records to be found in the United States were

at Trona, California. Fig. 12 shows the temperature at Trona on the hottest day of July, 1925. It ranges from 86 deg. at night to 115 deg. for a few hours in the afternoon, and the average is 105 deg. Because of the time re-

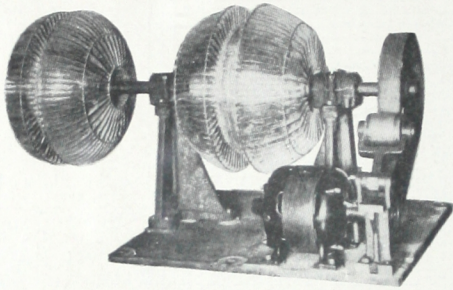


Fig. 15. An Air-cooled Audiffren Model

quired, however, for heat to leak into a box, the cycle for one day is not long enough to test the box. The temperature cycle for the worst three days at Trona, California, is shown

ture on the top shelf of the food compartment ranged from 46.5 deg. F. at night to 57.5 deg. in the afternoon.

Refrigeration Experience of the General Electric Company

Over a quarter of a century ago a French monk, the Abbé Audiffren, designed a hermetically sealed refrigerating machine. It is said that some of these machines are running in France after twenty-five years of service, never having been refilled with oil or gas. Fig. 14 shows a diagram of the interior of the Audiffren machine. Fig. 15 shows the exterior of a recent air-cooled model. It is a completely sealed dumb-bell, in which the compressor hangs on a pendulum. When the dumb-bell is rotated, one end gets cold, abstracting heat from the surrounding medium, and the other end becomes hot, giving up heat to the medium which surrounds it. There is no stuffing box. The power is transmitted from the outside to the inside by gravitation. The General Electric Company undertook the manufacture of this machine for the Audiffren

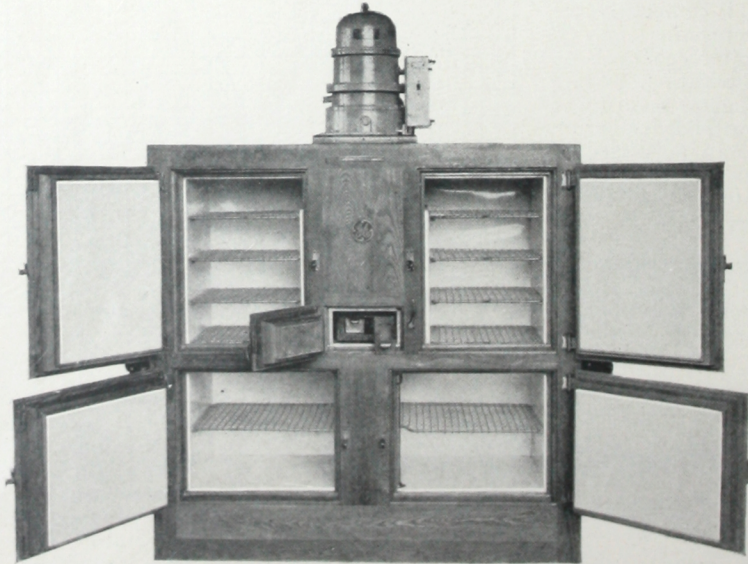


Fig. 16. Early General Electric Refrigerating Unit With Sealed-in Motor

in Fig. 13. The range is now from 82 deg. to 115 deg. and the average is only 102 deg. An artificially heated room was run through this cycle of temperature and it was found that in the General Electric refrigerator the tempera-

Company about fifteen years ago. Some of the first machines are still operating.

More than half a dozen years ago, the design of a domestic refrigerating machine was undertaken by this Company. Various models

of different designs were built. Seven stuffing box machines were constructed and placed in actual service for test purposes. The first of these operated successfully for one year and three months; another for eleven months, and the remainder failed in from two weeks to six months. The principal source of trouble was the stuffing box.

After various attempts, a water-cooled machine, shown in Fig. 16, was designed. It was a completely sealed machine with a motor inside. One of these machines ran for over five years without being refilled with gas or reoiled. Although this old machine differs in most of its details from the present machine,

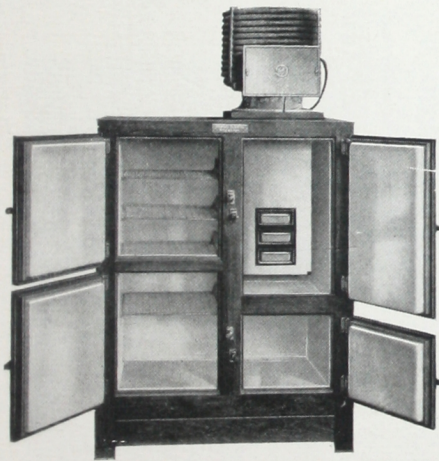


Fig. 17. Type OC-2 with Old Style Brine Tank

its long record of service demonstrates the possibility of constructing a machine with the motor inside which will operate successfully for over five years without even reoiling.

About twenty models of these original water-cooled machines were manufactured and put in service; only a few of them are still running, since they were constantly rebuilt as fast as improvements were suggested. Later the design was changed and air cooling adopted.

During the summer of 1926, above two thousand Type OC-2 air-cooled machines (Fig. 17) were sold as a large-scale experiment. This design has recently been superseded by a new one which is being manufactured in

two sizes—the smaller Type DR-2 machine (Fig. 18), for use with 5- and 7-cu. ft. food-storage boxes; and the larger Type DR-3 machine (Fig. 19), for use with 9-, 12-, and 16-cu. ft. food-storage boxes.

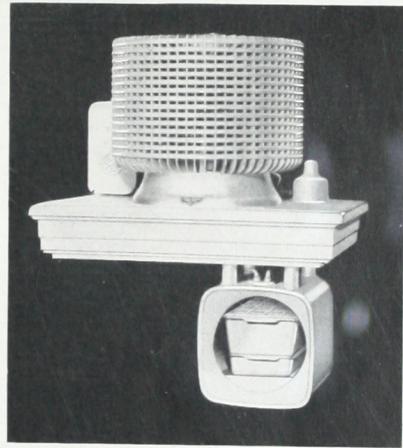


Fig. 18. DR-2 Refrigerating Unit

A diagrammatic sketch of the interior of the DR-2 machine is shown in Fig. 20.

The complete machine, mounted on a 5-cu. ft. refrigerator box, is shown in Fig. 21.

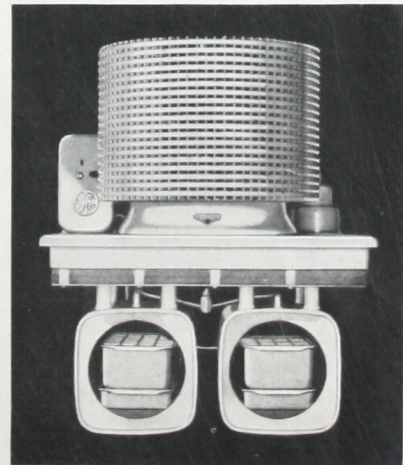


Fig. 19. DR-3 Refrigerating Unit

The installation of the machine in the box is simple and is usually accomplished with the lifter, Fig. 22.

Fig 23 shows the DR-3 machine mounted in a 16-cu. ft. box.

The advantages of these machines are as follows:

1. The oscillating cylinder compressor has been tried and proved reliable by a quarter of a century of service in the Audiffren machine.

2. By putting the motor inside, the stuffing box has been eliminated. A simple squirrel-cage motor, recognized as the most reliable type of motor, is used. It is enclosed so that no dirt can get into the windings and an inexhaustible supply of clean oil for the bearings is insured.

dropping it into the top of the box, as illustrated in Fig. 22.

4. Since the machine is on top, the hot air from it rises away from the box, allowing the box to operate in a cooler atmosphere than if it were bathed in hot air rising from the machine.

5. The sheet-steel cases have eliminated leaks due to porous castings.

6. The special metal-glass leads prevent leaks where the wires enter the case.

7. The joint around the bottom of the case is made with a tongue-and-groove lead seal.

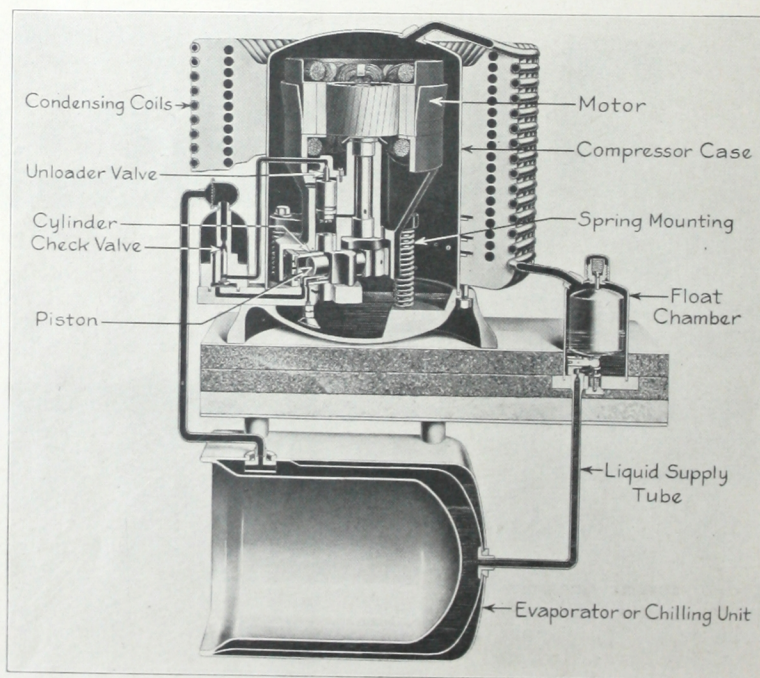


Fig. 20. Diagrammatic Sketch of the Interior of DR-2 Machine

One of the most successful domestic refrigerating machines in Europe has a somewhat similar totally enclosed unit. The motor in the Type DR-3 machine is especially interesting because the phase is split for both starting and running, by means of a capacitor instead of a resistance.

3. Locating the machine on top of the box has made it possible to eliminate all service valves and pipe joints. The machine, being a complete unit, can be installed by merely

8. The machine uses a float valve on the high-pressure side of the system. With this arrangement, it is necessary for the system to have exactly the right amount of gas in it. If there is too much, the compressor sucks liquid; if there is too little, the evaporator is inefficient. The hermetically sealed machine does not leak gas and, therefore, can maintain the correct quantity indefinitely. The float valve on the high-pressure side of the system has been retained because of successful ex-

9607
9

4"

perience with it in the Audiffren machine, and, because it does not waste valuable space within the food compartment of the box.

9. The machine has a force feed oiling system which insures a sufficient flow of oil and the oil never becomes over-heated. Since the oil is hermetically sealed within the casing, it can never become dirty or evaporate. Long experience with the Audiffren justifies the hope that the oil will last indefinitely.

Since the machine never has to be oiled, no oil will be spilled on it. Furthermore, oily vapors from frying food in a kitchen will naturally condense on the cooler objects in the room and the warm refrigerating machine

tion also prevents troubles due to tampering.

11. The machine is exceptionally quiet and vibrationless. The mechanism is mounted on springs and any noise or vibration originating in the mechanism has to be transmitted through the layer of gas which separates the mechanism from the casing.

12. Another innovation is the vitreous enamel freezing chamber. This feature makes the chamber very sanitary and easy to clean.

13. The freezing chamber has all the advantages of both the direct and indirect expansion systems. The ice cubes are frozen

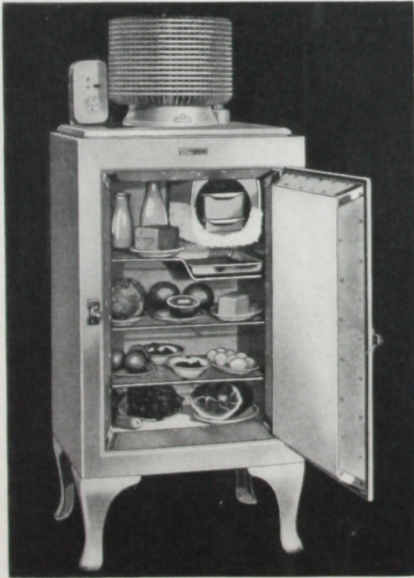


Fig. 21. DR-2 Unit with 5 Cu. Ft. Cabinet

is not likely to become greasy. Dust will collect on the horizontal surfaces, but these can be easily cleaned. Actual experience in kitchens has shown that dust does not collect on the vertical surfaces. The draft of air rising through the warm fins automatically keeps them free from dust.

10. The machine is characterized by a high degree of safety by reason of the total enclosure of all moving parts. This construc-

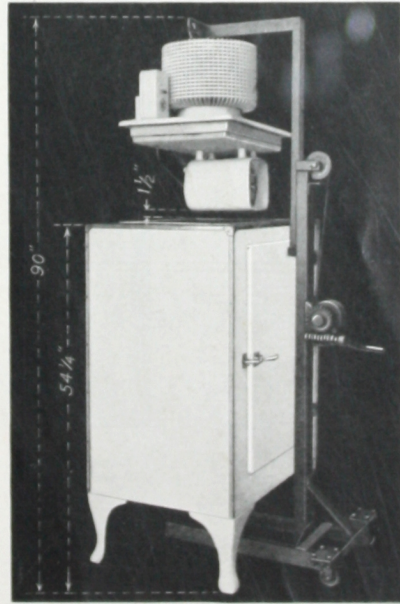


Fig. 22. Installation of Refrigerator Unit

by direct expansion, while the box is cooled indirectly through a glycerine and water freezing solution. Half a dozen pounds of this glycerine and water freezing solution in its latent heat of fusion provides as much cold storage as one hundred pounds of brine which merely stores heat in proportion to a temperature difference. It has the advantage that the area for heat transfer is increased, rather than reduced, by a moderate amount of

frosting. Therefore, the unit does not have to be defrosted as often as the coils usually used with direct expansion systems.

14. Tests have shown that these machines under extreme conditions—for example, operation in a 100-deg. room—will maintain temperatures under 50 deg. F. on the top shelf of the food compartment. This results from the fact that the boxes and machines were designed for each other.

15. Every machine before shipment is subjected to a refrigeration test in a 100-deg. F. room.

16. The machines are manufactured as complete units and are thoroughly inspected and tested for leaks. This makes it possible for an unskilled workman to install the units without the troubles which occur when unskilled workmen pipe a machine from cellar to existing box. Obviously, it would be impossible to give as thorough inspection and test on the user's premises.

17. Because of the self-contained feature of the machine and its exceptionally quiet operation, it is highly adaptable to modern apartment house conditions.

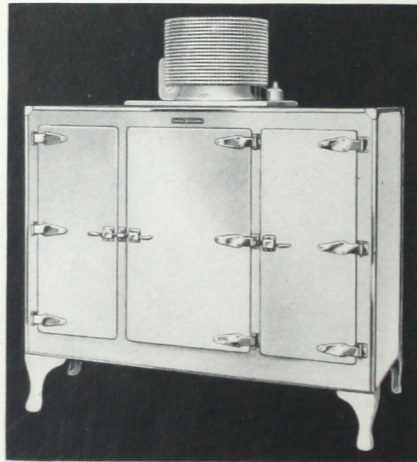


Fig. 23. DR-3 Machine with 16 Cu. Ft. Cabinet

